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AUTHOR(S): William L. Cabral, E-1

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Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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LIDAR techniques for search and rescue

William L. Cabral

Los Alamos National Laboratory
P. O. Box 1663
Los Alamos, New Mexico 87545

951 2470

Abstract

Four techniques for using LIDAR in Search and Rescue Operations will be discussed. The topics will include laser retroreflection, laser-induced fluorescence in the visible, laser-induced fluorescence during daylight hours, and laser-induced fluorescence in the UV. These techniques use high-repetition rate lasers at a variety of frequencies to induce either fluorescence in dye markers or retroreflection from plastic corner cubes on life preservers and other emergency markers.

Introduction

Bad weather and nighttime conditions have always hampered search and rescue efforts. However, with the new LIDAR (light detection and ranging) techniques that thrive on nighttime conditions, it might be possible to make some progress in this area.

Laser scattering or laser retroreflection has been used for a number of years for detecting clouds and ranging off the moon, but very little work has been done using corner cubes as markers in a remote sensing environment. Laser scattering has always been the most attractive of the LIDAR techniques because of its very strong signal return, and would make a good candidate for search and rescue. It is surprising how far away at night a reflector is visible in ones headlights. This is the same principle, except for the difficulty in distinguishing the reflectors from the reflections of the water, whereas on land it is easier because there are fewer background reflections.

There has been a lot of interest in using fluorescence LIDAR for remote sensing in the last few years. However, little interest has been directed toward man-induced species outside of sampling tracer dyes in the atmosphere,[1,2] which have covered relatively small geographical areas compared with distances involved in search and rescue. These techniques have been limited to fairly small concentrations of dye by volume compared with mixing in solution and should be scalable to substantially larger areas.

Laser retroreflection

This technique uses laser retroreflection from plastic corner cubes or glass microballoons.* These retroreflectors are sewn into life vests and rafts but should not be limited to these articles; for instance they could be just foldable pieces of plastic that could be spread out on the water, as well as on the land. Plastic retroreflectors are the same as the standard reflectors on cars, except they are made of flexible plastic that can be sewn on life vests or other emergency gear, and give a small return angular divergence. Whereas glass microballoons which are more commonly found on traffic signs, can be easily painted onto emergency gear, and give a little wider return angular divergence. These retroreflectors are currently placed on the life vests primarily to aid the Coast Guard at night in locating a person at close range with their search lights. The LIDAR technique will illuminate a much larger area and electronically integrate and display the return signal. which will decrease the burden on the pilot and increase the amount of area that can be covered.

Because these corner cubes might be very small compared with the illuminated area, it would be necessary to divide up the area into as many sampling areas as possible. This can be done with CCD solid-state cameras where a pixel definition of 488 x 350 resolution is not uncommon. Because the pixel distribution is uniform across camera and wide-angle lenses do not portray a linear distribution of distance across the face of the camera, the pixels on the edges of the viewing area will be collecting light from a disproportionately large area causing the background scattered light levels to be higher and the data less reliable. Also, at larger angles, the waves might cast shadows in the viewing area leaving holes in the search area. Therefore, it might not be practical to illuminate an area much over 90°.

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* 3M scotchlight.

The display console would be a standard video display, where the location of the aircraft would be depicted in the center of the screen and the top of the screen would be the direction the aircraft is heading. A large area would be illuminated for every laser slot, and for a confidence factor, the same point would be illuminated a number of times and would show up on the screen as a blip that would move consistently down the screen as the aircraft moves forward (Fig. 1). The advantage of this system is that it would enable searchers to continue into the night and still cover a large area of ocean. The disadvantages are that the sunlight would completely drown out the laser signal and that it would be difficult to develop a system that would overcome this background light; however, one possibility is to use one of the Fraunhofer lines, where there are gaps in the solar spectrum. The most promising one is at 393.33 nm and is approximately two orders of magnitude stronger than anything else in the visible spectrum. It might be possible to tune a laser to this line and avoid interference from background daylight.

Example: Given a helicopter flying at 100 mph, a frequency doubled Q-switched ND-YAG laser at 30 pps and 3 mJ per pulse, an altitude of 1,000 ft, and a viewing area of 90°, a number of things can be deduced; this gives a viewing area of 2,000 x 2,000 ft or 4M ft^2, with an illumination intensity of 7.5 x 10^{-4} mJ/ft^2. Using a camera with a pixel density of 488 x 350 and a sensitiviey of 5 V/uJ/cm^2 this gives us a pixel viewing area on the ocean surface of 12.1 ft^2 and a pixel sensitivity 2.31 x 10^6 V/uJ/pixel. If a retroreflector of 1 ft^2 with a return efficiency of 1% were placed in this area, if would give a return signal of 17.4 V on that pixel. Since the maximum signal allowed from the camera is 0.7 V, a filter might be necessary to reduce the signal. Flying at 100 mph gives us a flight time of 13.5 s over the target in the field of view and 405 laser samples, which would make it easy to differentiate the sporatic noise from the actual target because the sporatic noise will go away and the true signal should move consistently down the screen. With a 4 in. collecting lens and a reflection of ~ 4% off the surface, this gives us a return signal of 5.65 x 10^{-6} V/pixel/reflection. Since this number is for one reflection and there could be hundreds of reflections within a pixel viewing area, due to the hyperfine structure of the waves, the background level for each pixel could be much higher. Even if there were 1,000 reflections in the pixel viewing area, this would only increase the return signal to 5.65 x 10^{-3} V, which is still a signal-to-noise ratio greater than 1,000. Because the troughs of the waves are concave, the reflections would be most abundant at the bottom and could cause a disproportionately high-background return signal in the pixel viewing area. These reflections would probably show up as lines on the viewing screen as a number of pixels would be affected viewing along the trough. Another effect that might be seen on the screen would be the foamy peaks of the waves that could return a large amount of scattered light off of the foam but would appear more as sporatic noise that would come and go as a wave would break and the foam would disperse. Using an image intensifier tube as an electronic shutter with a variable gain (Fig. 2) it would be possible to adjust the gain so that the waves would just be visible. Then when a signal from a retroreflector impinges on the camera, the signal level will be so strong that it will cause severe blooming in the camera and appear on the screen as one bright spot as compared with the faint lines of the waves. It will be necessary to use the image intensifier tube as a shutter to shut out the initial scattered light from the laser firing; otherwise, the light would completely saturate the camera, causing it to take a few hundred microseconds to recover preventing the camera from picking up the signal return.
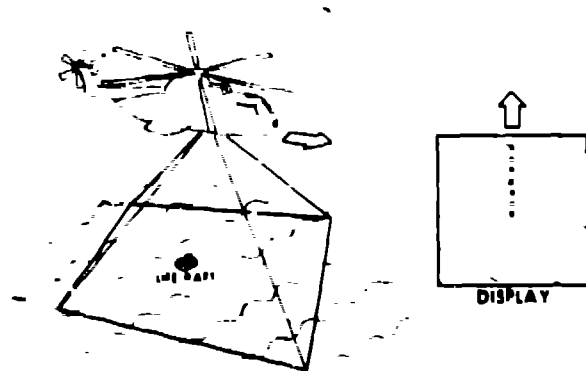

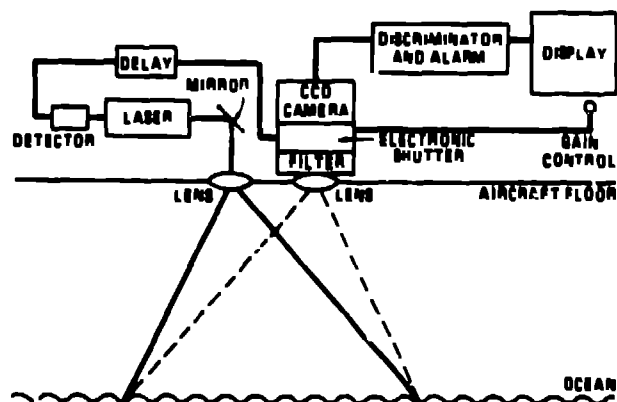Figure 1 PRINCIPLE OF OPERATION OF LASER RETROREFLECTOR

Figure 2 LASER RETROREFLECTOR
SCHEMATIC REPRESENTATION

Laser-induced fluorescence in the visible

Dye markers are not a new idea, they have been used for years as markers in the ocean. Typically, the dye marker used is sodium fluorescein with a fluorescence maximum at $\sim$ 531 nm. It is a relatively inexpensive dye that is released slowly from a package that is thrown into the water. Usually as the water currents flow in one general direction, the plume draws out in one direction becoming many kilometers long and many decameters wide and can last for a number of days depending on the turbidity of the water. When the sun goes down, the dye marker becomes fairly unusable, but with an aircraft equipped with a laser tuned to $\sim$ 501 nm and a detector tuned to the fluorescein fluorescence maximum at 531 nm, it should be possible to resolve the dye plume from a good distance away.

In some cases, the fluorescence background of the ocean might cause some difficulty in differentiating the dye plume, but the dye plume would still have its characteristic shape, it would just suffer in signal-to-noise ratio. The background fluorescence in the ocean primarily comes from detergents near cities, oil slicks, and chlorophyll. The detergents have very strong fluorescences, but fortunately they are all up around the UV region $\sim$ 410 nm (Ref. 3) and should pose no threat to the fluorescein fluorescence at 531 nm. The oil slicks from tankers are primarily diesel fuel and crude. The diesel fuel has a fluorescence maximum of $\sim$ 370 nm (Ref. 4) which should not pose much of a problem, but the crude has a peak of $\sim$ 530 nm (Ref. 4). However, crude does not mix well with water, and only the part on the surface will give a significant return. Unfortunately, the crude will disperse in the same characteristic plume as the dye, but with much less fluorescence efficiency then the dye. It might be useful to choose a dye marker more in the red region, such as rhodamine B with a peak at 588 nm at only 1.2 times the cost of sodium fluorescein. In this region, the fluorescene background is lower, but there is a strong chlorophyll $\underline{a}$ fluorescence at 685 nm (Ref. 5) that one needs to be careful of. Fortunately, it is a very sharp band compared with that of the crude and should pose little or no threat to the fluorescence background level at 588 nm.

A fluorescence LIDAR system has already been tested in the North Sea by U. Gehlhaar, K. P. Gunther, and J. Luther of the University of Oldenburg in Germany, with a detection limit of $\sim 10^{-10}$ g/cm^3 in rhodamine B. Their system used a high-energy dye laser at 536 nm and detected the return signal at 595 nm. "This system was developed specifically for the highly selective detection of fluorescent material (e.g., chlorophyll, tracer dyes, oils) of very low concentrations in the surface layer of the ocean." (From Gelhaar's report[6]). Whereas in search and rescue, the concentrations can be very high but lost in many square miles of open ocean.

Because the dye plume is spread out over a large area compared with the size of retroreflectors, it should be possible to do a sampling a number of feet apart in order to cover a much larger area in a shorter period of time. What I envision is a laser pulse as wide as the field of view will allow and only an inch or more long separated by a number of feet, followed by another pulse (Fig. 3). This can be achieved by cylindrical lenses in both the transmitter and receiver; the receiver can be segmented into a number of channels, each channel having its own detector. The information could be viewed in the cockpit on a square display, where the top row of lights will be the current laser shot and will be shifted down the display with every successive laser shot, yielding a representation of the dye plume as the aircraft passes overhead (Fig. 4). Exemer lasers
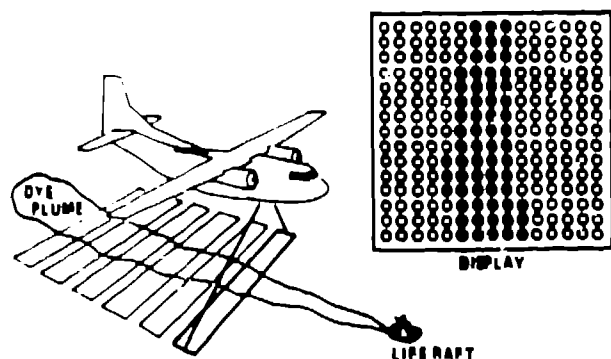

Figure 3.
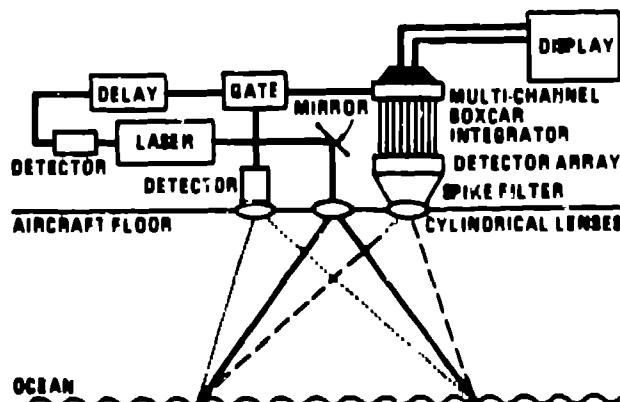PRINCIPLE OF OPERATION OF THE LASER FLUOROMETER

Figure 4. LASER FLUOROMETER
SCHEMATIC REPRESENTATION

make an attractive choice for this application because of their high-repetition rate. At 200 pps separated by 4 ft per pulse, this gives an aircraft speed of about 545 mph, and at an altitude of 10,000 ft, it should be possible to see at least a 20,000 ft wide field of view, which is ∿ 4 mi wide. Efficiently pumping sodium fluorescein or rhodamine B with UV light from exemer lasers is a problem. It might be possible to pump a dye laser with the exemer to provide a better pump source for the dye marker but at a cost of some output power. One of the alternatives might be to go to a lower repetition rate therefore lower air speed with a flashlamp-pumped dye laser that can put out considerably more energy, but is limited in power because of its inability to be effectively Q-switched. Another alternative is a frequency-doubled Q-switched ND-YAG laser at 532 nm. These lasers operate at up to 30 pps which, at 10 ft spacings, would be about 206 mph, but have the advantage of a high power output, as well as efficient pumping of rhodamine B with an absorption maximum of 544 nm. The laser of choice is still the exemer-pumped dye laser but depends primarily on the amount of fluorescence return from the dye marker to determine the possible altitude that is obtainable.

Laser-induced fluorescence during daylight hours

During the daylight hours, the fluorescent LIDAR technique mentioned above becomes much more difficult. If it becomes a significant timesaver, it may become necessary to look into extending its usefulness into the daytime hours. It might be possible to mix a dye called BBQ* with the sodium fluorescein or rhodamine B dye so that a XeCl exemer laser can be used straight out of the aircraft instead of pumping a dye as in the night-time application. The laser produces an output of 308 nm, which matches very closely the absorption maximum of BBQ at 307 nm. This gives a fluorescence maximum of ∿ 381 nm, which is about the same as the strong Fraunhafer line at 393 nm as mentioned earlier. It would then be necessary to use a boxcar integrator triggered by the scattered light from the surface to compare the background signal from the dye fluorescene level from the sun-light to the dye fluorescence level from the laser light. Since the fluorescence of the dye due to the sunlight would be very strong, it might be possible to distinguish the dye by using a spike filter at the Fraunhafer line on a regular vidicon camera. This is similar to work being done by the US Geologic Survey to look for minerals that fluoresce in this usually dark part of the spectrum. This might be very promising especially at very high altitudes where the field of view can be quite large.

Laser-induced fluorescence in the UV

This technique is very similar to the fluorescence systems described above except for its application. It would be desirable for a pilot shot down behind enemy lines to be able to disperse a dye marker into a lake or stream to mark his location without turning the whole place orange. Using the same technique as the laser induced fluorescence during daylight hours except for just using straight BBQ dye, it should be possible to disperse this colorless powder into the environment where it would fluoresce at 373-391 nm, which is beyond the limit of the visible spectrum. This would only be visible to the LIDAR system using the Fraunhafer line during the day or even better at night when the background fluorescence level would be lower and also be easier to get behind enemy lines.

Conclusion

These are just a few possibilities for using LIDAR techniques in search and rescue. Because the applications are so varied and a number of approaches can be applied to each one, the previously mentioned techniques might not be the best tradeoffs for that particular application, but because they show such great promise, these techniques should at least be researched further to find out the real feasibility of these new search and rescue developments.

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* Exciton Chemical Corp.

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